REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 2006	USARIEM Technical Report

4. TITLE AND SUBTITLE
Physiological Responses to Heat Stress in the Joint Protective Aircrew Ensemble (JPACE) Coverall with Varied Protective Equipment

5. FUNDING NUMBERS

6. AUTHOR(S)
B.S. Cadarette, L. Levine, S.B. Robinson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Thermal and Mountain Medicine Division
U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER
T07-02

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Same as #7 above

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The Joint Protective Aircrew Ensemble (JPACE) Program addresses the below-the-neck chemical and biological (CB) protective garment needs for fixed wing (TACAIR) and rotary wing (RW) aviators and combat vehicle crew (CVC). This study evaluated heat strain while volunteers wore the JPACE and the USAF CWU-66/P coveralls (66/P) with aviation life support equipment and armored vehicle MOPP level 4 uniform configurations in 10 tests (2 CVC, 4 TACAIR, and 4 RW). Each day, subjects completed repeated work/rest cycles on a treadmill for an approximate metabolic production of 300 W. Core temperature, skin temperature, heart rate, body weight, perceived exertion, thermal sensation, and thermal comfort were measured. Sweating rate, evaporative cooling, and rate of heat storage were calculated. CVC tests indicate that the JPACE coverall does not meet the requirement of creating heat strain no greater than a currently fielded CB protective coverall as represented by the 66/P. TACAIR tests show that wearing the ATAGS anti-G suit increases heat strain regardless of which coverall is worn with it. RW tests using the Air Warrior microclimate cooling system indicate the benefit that the liquid-cooled vest would provide. Adding the Air Warrior or similar microclimate cooling system to the JPACE program should be considered to reduce heat strain for all users.

14. SUBJECT TERMS
Aircrew, CB Clothing, core temperature, microclimate cooling, exercise

15. NUMBER OF PAGES
36

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unclassified

USARIEM TECHNICAL REPORT T07-02

PHYSIOLOGICAL RESPONSES TO HEAT STRESS IN THE JOINT PROTECTIVE AIRCREW ENSEMBLE (JPACE) COVERALL WITH VARIED PROTECTIVE EQUIPMENT

Bruce S. Cadarette
Leslie Levine
Scott B. Robinson

Thermal and Mountain Medicine Division

December 2006

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

DISCLAIMER STATEMENTS

Approved for public release; distribution is unlimited.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Army or the Department of Defense.

The investigators have adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 45 CFR Part 46.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and the USAMRMC Regulation 70-25 on the use of volunteers in research.

Any citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement of approval of the products or services of these organizations.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE PAGE

List of Tables

ACKNOWLEDGMENTS

The author acknowledges Nancy Southwick and Tom Hart for their daily assistance in the successful completion of this study, and Kristin Bowling and Shannon McCook for their technical expertise in both conducting the study and analyzing data for development of this manuscript.

LIST OF ABBREVIATIONS

ALSE - Aviation Life Support Equipment

ATAGS - Positive Pressure Anti Gravity Suit

CB - Chemical/biological

CVC - Combat Vehicle Crew

JPACE – Joint Protective Aircrew Ensemble

JSLIST – Joint Service Lightweight Integrated Suit Technology

RW – Rotary Wing

TACAIR – Fixed Wing Tactical Aircraft

13B/P – Anti Gravity Suit

66/P – U.S. Air Force Chemical/Biological Protective Coverall

EXECUTIVE SUMMARY

The Joint Protective Aircrew Ensemble (JPACE) Program is a joint service program including U.S. Army, U.S. Navy, U.S. Marine Corps, U.S. Air Force, and U.S. Special Forces Command participation. JPACE addresses the below-the-neck chemical and biological (CB) protective garment needs for all fixed wing and rotary wing aviation personnel and combat vehicle crew (CVC) personnel. This study evaluated heat strain in volunteers during exercise-heat stress experiments conducted while they wore the JPACE and the currently fielded USAF CWU-66/P coveralls (66/P) with accepted aviation life support equipment (ALSE) and armored vehicle MOPP level 4 uniform configurations for a total of 10 garment tests.

We compared heat storage as calculated by change in mean body temperature over the exposure time, change in core temperature, sweating rate, evaporative cooling, change in heart rate, and performance time in volunteers wearing the JPACE candidate coverall and the currently fielded 66/P coverall in equivalent CB configurations during light intensity exercise (~300 W) in hot environments (11). We studied CB configurations for TACAIR personnel, CVC personnel, and RW personnel. The four TACAIR tests were conducted to examine differences between the JPACE and the currently fielded 66/P coverall with two versions of anti-G suits: the ATAGS and the 13B/P. TACAIR tests were designated JPACE-ATAGS, JPACE-13B/P, 66/P-ATAGS, and 66/P-13B/P. In the two CVC tests we examined differences between the JPACE and 66/P coverall with full CB protective gear. CVC tests were designated JPACE-CVC and 66/P-CVC. The four RW tests were conducted to examine the differences between JPACE and 66/P coverall with (B) and without (NB) supplementary air blown to the protective face mask. In the four RW tests the Air Warrior liquid microclimate cooling system (a standard component of the RW ALSE) was worn and provided cooling to the subjects at all times. RW tests were designated JPACE-B, JPACE-NB, 66/P-B, and 66/P-NB.

The four TACAIR tests were conducted at 30.0°C T_{db}, 10.5°C T_{dp} (86°F, 30% rh, 2 mph wind). The two CVC tests and four RW tests were conducted at 37.8°C T_{db}, 18.0°C T_{dp} (100°F, 30% rh, 2 mph wind). Rectal core temperature, skin temperature, heart rate, and body weight were measured. Whole body sweating rate, evaporative cooling, and rate of heat storage were calculated from the measured values. Subjective measures of perceived exertion, thermal sensation, and thermal comfort were also measured. Additionally, subjects completed tests of simple visual reaction time, the Psychomotor Vigilance Test, each day. Each day subjects completed repeated work/rest cycles of three 30-minute walks separated by two 15-minute rest periods for a mean-weighted metabolic rate of 307±47 W.

Six subjects completed the four tests in the TACAIR configurations. Results indicated that the ATAGS anti-G uniform had more impact on physiological responses than either of the chemical protective coveralls. In general, there was a greater level of heat strain when either the JPACE or 66/P coverall was worn with the ATAGS than when either one was worn with the 13B/P anti-G suit.

Five subjects completed the two tests in the CVC configurations. Results indicated that, in general, there was a greater level of heat strain during the test while wearing the JPACE coverall compared with the 66/P coverall.

Eight subjects completed the four tests in the RW configurations. Results indicated that there were no differences in level of heat strain among the configurations in these tests where subjects always received microclimate cooling.

Results from the CVC tests clearly show that the JPACE coverall does not meet the requirement of creating heat strain no greater than a currently fielded CB protective coverall for pilots, as represented by the 66/P. A sidelight of the tests in the TACAIR configurations is that the use of the ATAGS anti-G suit adds a significantly greater level of heat strain to the user regardless of which coverall is worn with it. Finally, the results of the RW tests using the Air Warrior microclimate cooling system indicate the benefit that the liquid-cooled torso vest would provide the air crew or combat vehicle crew. Adding the Air Warrior system or similar microclimate cooling to the JPACE program should be considered to reduce the level of heat strain for all users.

INTRODUCTION

This study supported the Joint Protective Aircrew Ensemble (JPACE) Program, a joint service program including U.S. Army, U.S. Navy, U.S. Marine Corps, U.S. Air Force, and U.S. Special Forces Command participation. JPACE addresses the below-the-neck chemical and biological (CB) protective garment needs for all fixed wing and rotary wing aviation personnel and combat vehicle crew (CVC) personnel. We evaluated heat strain in volunteers during exercise-heat stress experiments conducted while they wore the JPACE and the currently fielded USAF CWU-66/P coveralls (66/P) with accepted aviation life support equipment (ALSE) and armored vehicle Mission Oriented Protective Posture level 4 (MOPP 4) uniform configurations for a total of 10 garment tests. Data from these tests are used in the evaluation process of the JPACE program.

New clothing configurations in the JPACE program are required to reduce heat strain relative to currently fielded CB protective clothing configurations. The JPACE protective clothing includes body coverage, as well as required interfaces for hand, foot, and respiratory protection. The JPACE program utilizes the Joint Service Lightweight Integrated Suit Technology (JSLIST) Program for hand and foot protection. The Joint Service Aviation Mask (JSAM) Program will provide future head, eye, and respiratory protection for aviation users of JPACE, while the Joint Service General Purpose Mask (JSGPM) Program will provide this future protection for CVC personnel. There are currently four legacy masks providing head, eye, and respiratory protection to JPACE users (M-45 (USA), MBU-19/P (USAF), A/P-22/P-14(V) (USN/USMC), and M-42 (CVC)).

The commercially made garment chosen for the JPACE program is a CB protective coverall designed to be worn over personal underwear, and under the additional protective equipment worn by both aircrew and armored vehicle crew.

The JPACE coverall is designed to be compatible with the other components of fixed wing tactical aircraft (TACAIR) and rotary wing (RW) ALSE, such as helmets, gloves, footwear, pressure suits, and anti-exposure garments. The coverall must be suitable to protect aviators and CVC personnel from a CB environment while allowing them to perform all normal and emergency maneuvers required for combat operations. When combined with CB head-eye-respiratory equipment, the JPACE coverall must provide an integrated, CB protection system during in-flight and armored vehicle operations.

Current aircrew CB flight garments (represented in this study by the USAF 66/P coverall) are considered too heavy, too bulky, and too restrictive for necessary movement. In addition, the flight garments hasten both the onset and level of fatigue, reduce mobility, limit visibility, and restrict ability to safely fly the aircraft and perform mission functions. Finally, the current flight garments impose significant heat stress on the wearer, similar to other CB protective clothing, which is known to negatively impact military performance (3, 7, 8, 9, 10). The USAF 66/P coverall used as the control in these experiments was chosen by the JPACE program principally for two reasons: 1) the 66/P is the only currently fielded CB flight garment that is a coverall like the JPACE candidate, and 2) the 66/P creates the lowest level of heat stress of the currently fielded CB protective garments. The complete list of all clothing and equipment worn during testing is shown in Table 1.

We compared heat storage as calculated by change in mean body temperature over the exposure time, change in core temperature, sweating rate, evaporative cooling, change in heart rate, and performance time in volunteers wearing the JPACE candidate coverall and the currently fielded 66/P coverall in equivalent CB configurations during light intensity exercise (~300 W) in hot environments (11). We studied CB configurations for TACAIR personnel, CVC personnel, and RW personnel. The four TACAIR tests were conducted to examine differences between the JPACE and the currently fielded 66/P coverall with two versions of anti-G suits: the ATAGS and the 13B/P. The two CVC tests were conducted to examine differences between the JPACE and 66/P coverall with full CB protective gear (masks, gloves, and overboots). The four RW tests were conducted to examine the differences between JPACE and 66/P coverall with and without supplementary air blown to the protective face mask. In the four RW tests, the Air Warrior liquid microclimate cooling system (a standard component of the RW ALSE) was worn and provided cooling to the subjects at all times.

Table 1. Items worn for the ten tests in this study. Included are eight Aviation Life Support equipment tests (four Fixed Wing Tactical Aircraft [TACAIR] tests and four Rotary Wing [RW] tests), and two Combat Vehicle Crew (CVC) tests. Each of the five configurations shown below is worn with both JPACE and 66/P Coveralls for a total of ten tests.

	Aviation Life Support Equipment				**CVC**
Five Configurations	**TACAIR, 13 B/P**	**TACAIR ATAGS***	**RW w/ and w/o blower**		
Test Conditions	30°C (86°F), 30% rh, 0.9 m·sec^{-1} (2 mph) wind		37.8°C (100°F), 30% rh, 0.9 m·sec^{-1} (2 mph) wind		
JPACE and 66/P Coverall With Neck Insert			X	X	X
JPACE and 66/P Coverall *w/o* Neck Insert	X	X			
Spall Vest					X
Microclimate Cooling Garment			X	X	
AIRSAVE Body Armor			X	X	
Survival Vest: AIRSAVE with Integrated Harness			X	X	
13B/P Anti-G Suit	X				
ATAGS G-suit		X			
Counter Pressure Vest		X			
Torso Harness	X	X			
Survival Vest: SRU-21/P	X	X			
HGU-56/P Helmet			X	X	
HGU-68/P Helmet	X	X			
CVC helmet					X
M-45 Mask with Hood			X w/ blower	X w/o blower	X w/o blower
A/P-22P-14(v) Mask with Blower	X	X			
Chem. Gloves w/ Liner	X	X	X	X	X
GVO/BVO*			X	X	X
Chem. Sock	X	X			
Combat Boot	X	X	X	X	X

*ATAGS: Positive Pressure Anti-G System

*GVO: Green Vinyl Overboot; BVO: Black Vinyl Overboot

METHODS

EXPERIMENTAL DESIGN, PROCEDURES, AND MEASUREMENTS

Subjects

Seven male and one female soldier were recruited to participate as volunteer test subjects in this study. Before testing began, all volunteers were fully briefed, both orally and in writing, on the purpose and risks of the study, and consented to participate in the research. A medical officer cleared the volunteers as healthy after a physical examination and medical history review.

Preliminary Tests

On one day the volunteers were fitted to the two coveralls and additional protective equipment listed in Table 1 to be worn during garment tests. They also took part in familiarization sessions to practice walking on the treadmill while wearing all of the test equipment. During these familiarization sessions, the metabolic rates during exercise and rest were measured to determine the appropriate walk/rest cycles to simulate the light work performed by pilots during flight operations (12). The appropriate speed and grade combination thus derived was used for the garment tests. Preliminary tests included anthropometric measures of height, weight, and subcutaneous skinfold thickness to estimate percent body fat (5). The volunteers completed at least 2 days of exercise-heat exposure preceding garment tests to reduce the physiological strain levels and variability to exercise-heat stress, and for habituation to the experimental methods. During the preliminary heat exposure, the volunteers walked on the treadmill at 1.56 m•sec-1 at a 4% grade for 100 minutes, with a 10-minute rest after each 50 minutes of exercise. The climatic conditions were 35°C, 50% rh (wind speed, 0.9 m·sec-1). Rectal temperature and heart rate were measured throughout all heat stress procedures. During these sessions, volunteers wore shorts, t-shirts, and athletic shoes. Water and a commercial glucose/electrolyte drink were available *ad libitum* during the exercise sessions. Volunteers were encouraged to drink during both exercise and rest. Pre- and post-exercise weights were recorded daily. If necessary, at the end of each heat familiarization, the volunteers drank sufficient liquid to return within 1% of their first morning weight to assure that they did not undergo a progressive dehydration that would negatively affect core temperature and heart rate responses.

Garment Tests

The volunteers completed five garment tests in both the JPACE and the 66/P coveralls with appropriate survival equipment for a total of 10 tests, as shown in Table 1. Each day the volunteers additionally wore spandex shorts, a standard military t-shirt, and a sports bra for the female volunteer.

The four TACAIR tests were conducted at 30.0°C Tdb, 10.5°C Tdp (86°F, 30% rh, 2 mph wind). The two CVC tests and four RW tests were conducted at 37.8°C Tdb, 18.0°C Tdp (100°F, 30% rh, 2 mph wind). The volunteers were provided with 2-quart canteens of water for *ad lib* drinking during each of the garment tests. The canteens were refilled as necessary during the tests. Canteens were weighed before and after each refill to determine water consumption. Volunteers were weighed both dressed and minimally clothed before and after each test. Whole body sweating rate was calculated from the change in minimally clothed body weight during the garment tests, with corrections made for water intake. Evaporative sweating was calculated from the change in fully clothed body weight during the garment tests, with corrections made for water intake.

During all heat exposures, flexible rectal thermistor probes inserted 10 cm beyond the anal sphincter were used to measure core temperature, and heart rate was obtained using Polar™ heart rate watches. Additionally, during the garment tests, skin temperatures (T_{sk}) were measured using thermistors at four-sites (calf, thigh, forearm, chest).

Rate of heat storage (S) in $W \cdot m^{-2}$ was calculated from the equation $S=[(m_b \cdot c_b)/A_D] \cdot (dT_b/dt)$, where m_b is the mean body weight (kg), during each garment test; c_b is the specific heat constant ($0.965\ W \cdot h \cdot {}^\circ C^{-1} \cdot kg^{-1}$); A_D is the DuBois surface area (m^2); dT_b is the change in mean body temperature (°C), where $T_b=0.1 \cdot T_{sk}+0.9 \cdot T_{re}$ in the tests with no microclimate cooling and $T_b=0.2 \cdot T_{sk}+0.8 \cdot T_{re}$ in the tests with microclimate cooling; and dt is the exposure time (h).

The volunteers were asked to rate their perception of effort (RPE) based on the standard Borg scale (2), to rate their perceived thermal sensations (TS) based on a routinely used scale modified from Gagge (6, 13), and to provide ratings of thermal comfort (TC) on a standard scale derived from Berglund (1), throughout the course of the garment tests. Volunteers rated RPE, TS, and TC once during the last minute of each rest and exercise session. The RPE, TS, and TC scales were introduced to the volunteers prior to testing. They practiced the procedures during the preliminary heat exposures, being asked to rate their perceptions using the RPE, TS, and TC scales twice during each session. The subjects were also asked to complete tests of simple visual reaction time, the Psychomotor Vigilance Test (PVT), as derived from Dinges and Powell (4), during rest breaks in heat acclimation and garment tests.

STATISTICAL ANALYSIS

Responses were compared between the coveralls in each equipment configuration. Specifically, for the TACAIR tests, both the JPACE coverall and the 66/P coverall were worn with both ATAGS and 13B/P anti-gravity suits, aviation face masks, and appropriate TACAIR ALSE for the MOPP 4 configuration. The four configurations compared in these tests are designated as

1) JPACE-ATAGS, 2) JPACE-13B/P, 3) 66/P-ATAGS, and 4) 66/P-13B/P. For the CVC tests, the JPACE coverall and 66/P coverall were worn with mask, boots, and gloves in the MOPP 4 configuration and with body armor. The two configurations compared in these tests are designated as 1) JPACE-CVC and 2) 66/P-CVC. For the RW tests, both the JPACE coverall and the 66/P coverall were worn with (B) and without (NB), a positive pressure blower to the face mask, appropriate RW ALSE for the MOPP 4 configuration, body armor, and microclimate cooling using the U.S. Army Air Warrior system. The four configurations compared in these tests are designated as 1) JPACE-B, 2) JPACE-NB, 3) 66/P-B, and 4) 66/P-NB.

A one way analysis of variance with uniform configuration as the independent variable was used to analyze the dependent variables of calculated rate of heat storage, sweating rate, evaporative cooling, and endurance time among the uniform configurations. A two way analysis of variance with time as the additional independent variable was used to analyze the dependent variables of core temperature, mean weighted skin temperature (MWST), heart rate, RPE, TS, TC, and PVT. PVT results were analyzed for mean response time, total responses, and valid responses. When significant main effects were found in any analyzed data, Tukey's test of critical difference was used for post hoc analysis. Analyses on all variables except endurance time were calculated only on the total number of subjects who completed the entire 120 minutes heat exposure in each uniform configuration. Therefore, analyses are completed on six subjects in TACAIR, five subjects in CVC, and eight subjects in RW. No comparisons were made among the TACAIR, CVC, and RW uniform configurations.

RESULTS

Eight volunteers (seven male and one female) were studied. All results are reported as the mean ± standard deviation (SD). The age, height, weight, body surface area (A_D), and percent body fat of the volunteers were 21±3 years, 172±4 cm, 77.7±9.2 kg, 1.90±0.12 m^2, and 19.5±6.3% body fat.

TACAIR RESULTS

Endurance times for all eight subjects in the four TACAIR configurations were JPACE-ATAGS 111±16 minutes; 66/P-ATAGS 120±0 min; JPACE-13B/P 120±0 min; and 66/P-13B/P 120±0 min. There were no significant differences among the endurance times. Two volunteers did not complete the JPACE-ATAGS tests; both stopped at 80 minutes, one complaining of nausea and difficulty taking a breath, and one complaining of nausea and feeling hot. The remaining TACAIR analyses were conducted on the six subjects who completed 120 minutes of testing in each of the four configurations.

Figure 1 shows heat storage (S) in each of the four TACAIR configurations. The values are JPACE-ATAGS, 35±9 $W \cdot m^{-2}$; 66/P-ATAGS, 28±5 $W \cdot m^{-2}$; JPACE-13B/P, 20±8 $W \cdot m^{-2}$; and 66/P-13B/P, 14±8 $W \cdot m^{-2}$. S in JPACE-ATAGS was significantly greater than in JPACE-13B/P and 66/P-13B/P ($p<0.05$) and approaches significance versus 66/P-ATAGS ($p=0.055$). S in 66/P-ATAGS was significantly greater than in both configurations with the 13B/P anti-G garment, and S in JPACE-13B/P approached significance versus 66/P-13B/P ($p<0.07$).

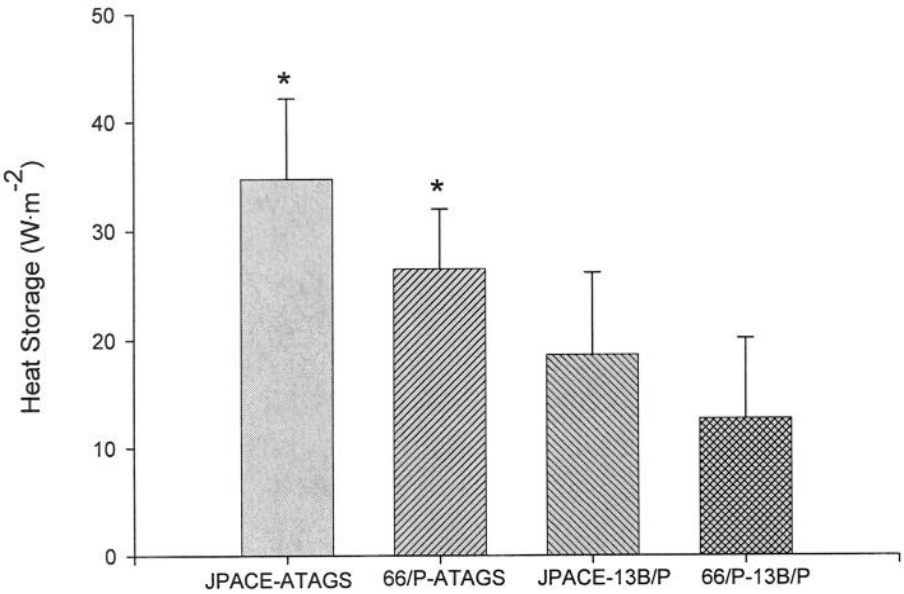

Figure 1. Mean ± SD heat storage during the TACAIR tests. * Both ATAGS configurations significantly greater than both 13/BP configurations ($p<0.05$).

Figure 2 shows core temperature changes over time in each of the four TACAIR configurations, with significant differences between both ATAGS configurations and both 13B/P configurations appearing at 80 minutes ($p<0.05$). Final core temperature values for the four uniform configurations at 120 minutes are JPACE-ATAGS, 38.6±0.3°C; 66/P-ATAGS, 38.4±0.3°C; JPACE-13B/P, 37.8±0.3°C; and 66/P-13B/P, 37.5±0.2°C. Final core temperature in both JPACE-ATAGS and 66/P-ATAGS were significantly greater than in the other two uniform configurations ($p<0.05$). Additionally, final core temperature in JPACE-13B/P was significantly greater than in 66/P-13B/P.

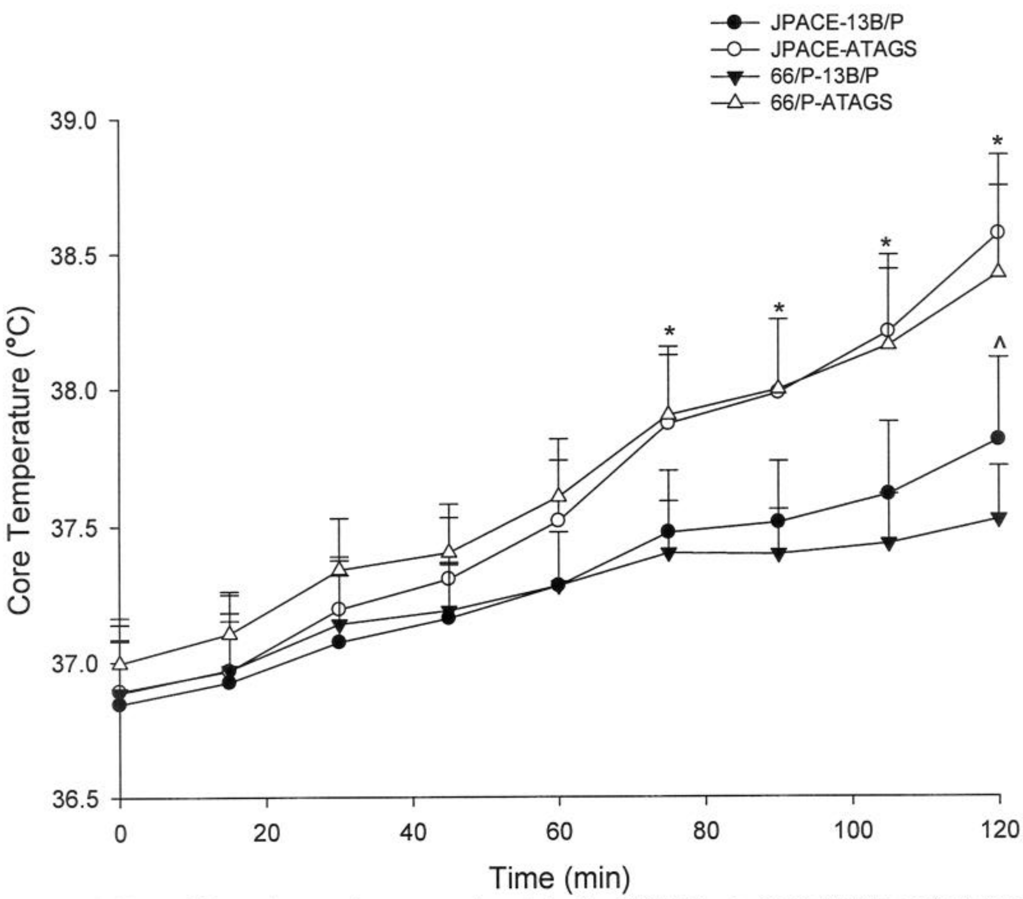

Figure 2. Mean ±SD core temperatures across time during the TACAIR tests. *Both ATAGS configurations significantly greater than both 13B/P configurations ($p<0.05$). ^JPACE-13B/P significantly greater than 66/P-13B/P ($p<0.05$).

Figure 3 shows MWST changes over time in each of the four TACAIR configurations, with significant differences between both ATAGS configurations and both 13B/P configurations appearing at 45 minutes ($p<0.05$). Final MWST values for the four configurations at 120 minutes are JPACE-ATAGS, 36.9±0.6°C; 66/P-ATAGS, 36.2±0.6°C; JPACE-13B/P, 35.9±0.5°C; and 66/P-13B/P, 35.2±1.0°C. Final MWST in JPACE-ATAGS was significantly greater than in all other uniform configurations ($p<0.05$). Final MWST in 66/P-ATAGS was significantly greater than in 66/P-13B/P ($p<0.05$). Final MWST in JPACE-13B/P was significantly greater than in 66/P-13B/P ($p<0.05$).

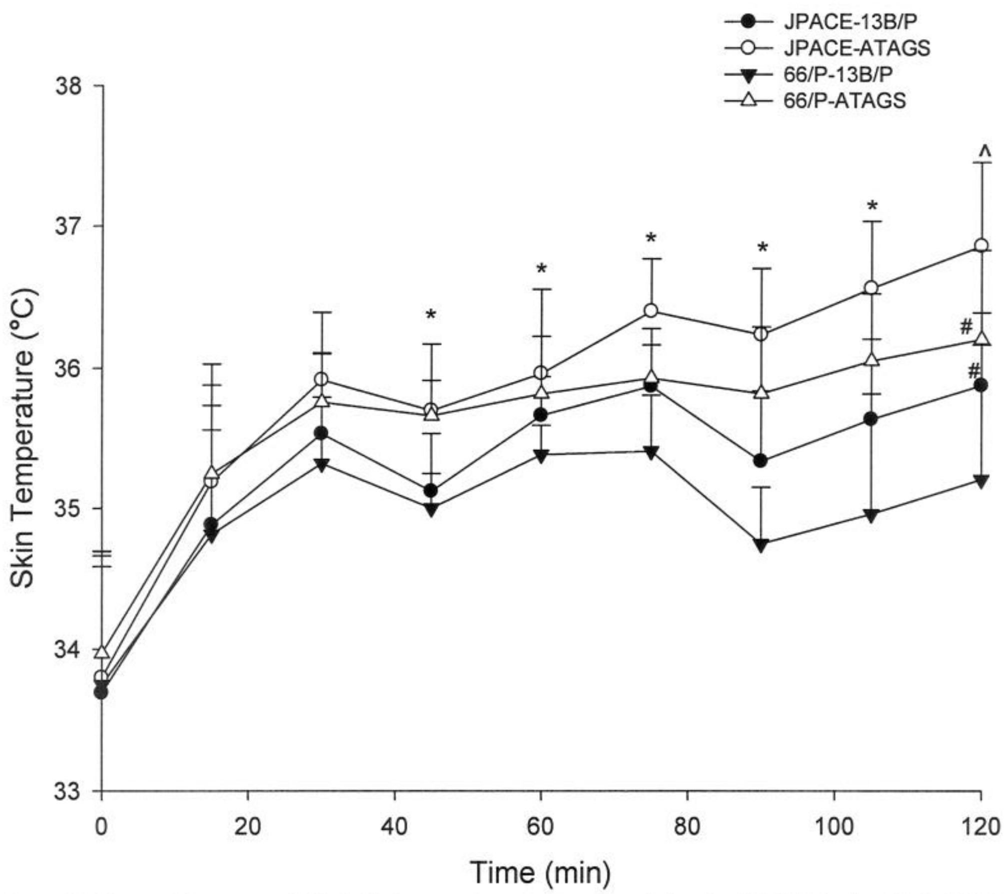

Figure 3. Mean ±SD mean weighted skin temperatures across time during the TACAIR tests. *Both ATAGS configurations significantly greater than both 13B/P configurations ($p<0.05$). ^JPACE-ATAGS significantly greater than all other configurations ($p<0.05$). # 66/P-ATAGS and JPACE-13B/P significantly greater than 66/P-13B/P ($p<0.05$).

Figure 4 shows heart rate changes over time in each of the four TACAIR uniform configurations, with significant differences between both ATAGS configurations and both 13B/P configurations appearing at 60 minutes (Figure 4). Final HR values for the four configurations at 120 minutes are JPACE-ATAGS, 160± 20 b· min^{-1}; 66/P-ATAGS, 153±13 b· min^{-1}; JPACE-13B/P, 131±18 b· min^{-1}; and 66/P-13B/P, 118±15 b· min^{-1}. Final HR in JPACE-ATAGS and 66/P-ATAGS were significantly greater than in both JPACE-13B/P and 66/P-13B/P ($p<0.05$). Additionally, final HR in JPACE-13B/P was significantly greater than in 66/P-13B/P ($p<0.05$). A missing data point value was calculated for heart rate at minute 80, and the degrees of freedom in the ANOVA was corrected for this statistical manipulation.

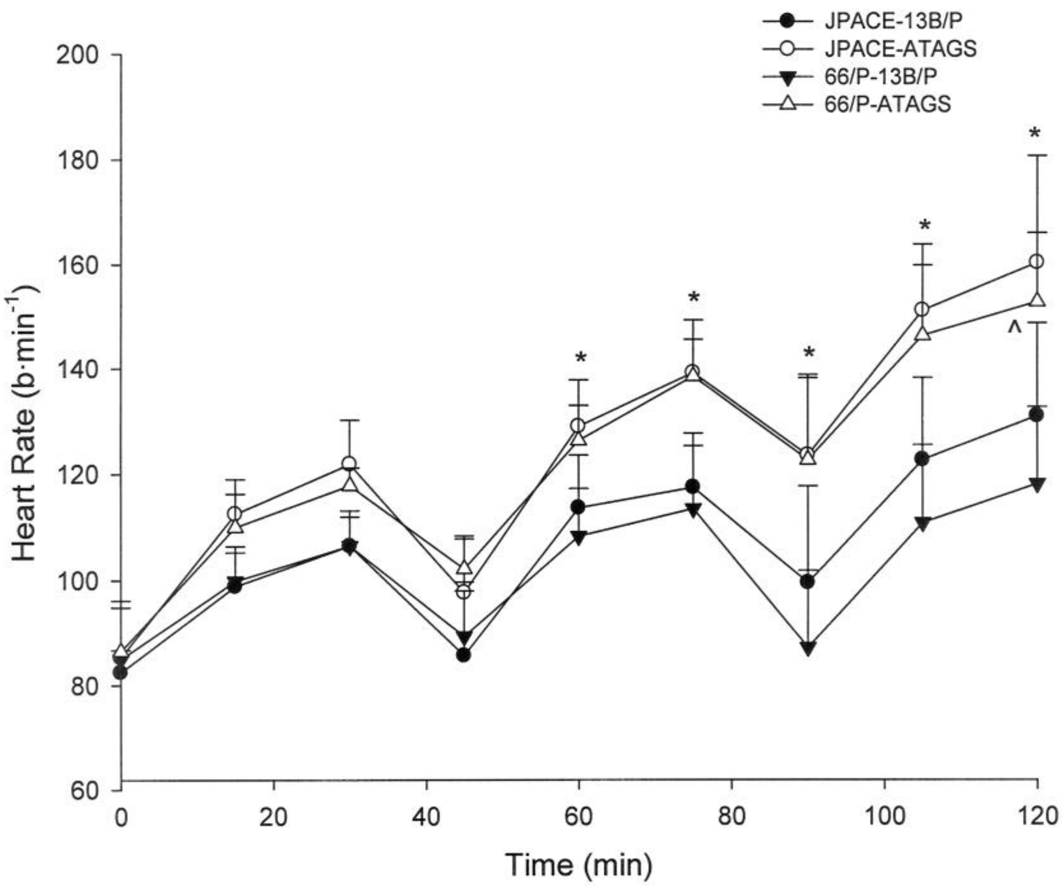

Figure 4. Mean ±SD heart rates across time during the TACAIR tests. *Both ATAGS configurations significantly greater than both 13B/P configurations ($p<0.05$). ^JPACE 13B/P significantly greater than 66/P-13B/P ($p<0.05$).

Figure 5 shows sweating rates in each of the four TACAIR configurations. The values are JPACE-ATAGS, 17±8 $g \cdot min^{-1}$; 66/P-ATAGS, 16±8 $g \cdot min^{-1}$; JPACE-13B/P, 13±6 $g \cdot min^{-1}$; and 66/P-13B/P, 10±4 $g \cdot min^{-1}$. Sweating rates in both JPACE-ATAGS and 66/P-ATAGS configurations were significantly greater than in the 66/P-13B/P configuration ($p<0.05$).

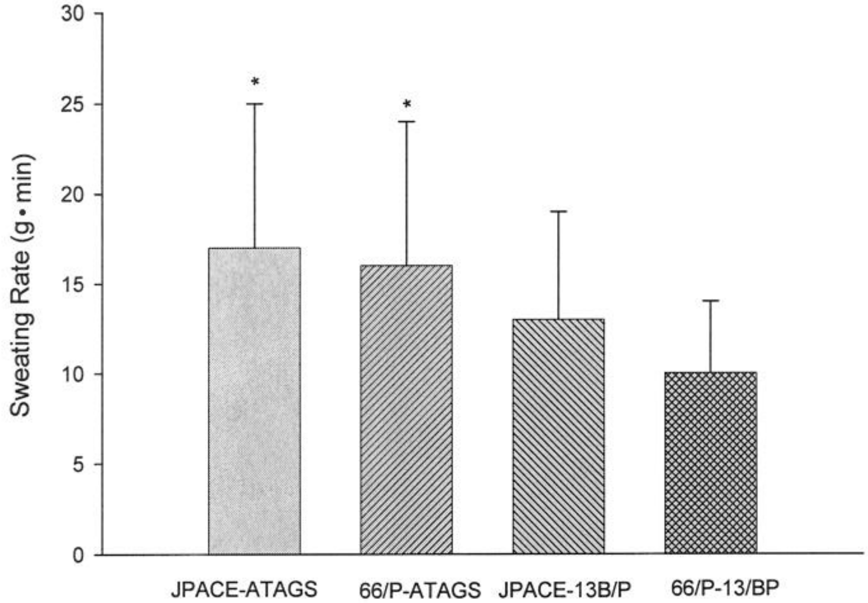

Figure 5. Mean ±SD sweating rates during the TACAIR tests. *Both ATAGS configurations significantly greater than 66/P-13/BP (p<0.05).

Figure 6 shows evaporative cooling rates in each of the four TACAIR configurations. The values are JPACE-ATAGS, 89±45 $W \cdot m^{-2}$; 66/P-ATAGS, 95±32 $W \cdot m^{-2}$; JPACE-13B/P, 125±30 $W \cdot m^{-2}$; and 66P-13B/P, 98±24 $W \cdot m^{-2}$. There were no significant differences in evaporative cooling rates among the four uniform configurations.

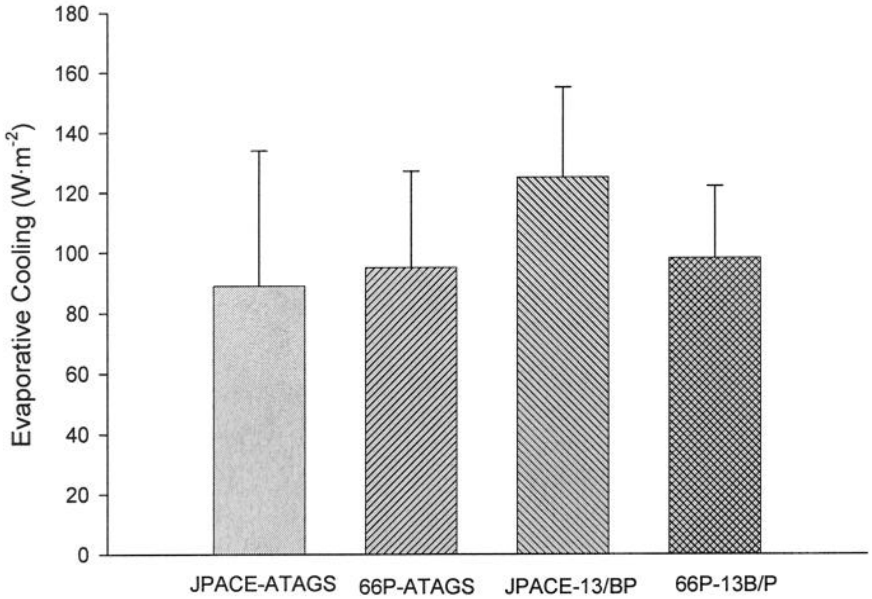

Figure 6. Mean ±SD evaporative cooling rates during the TACAIR tests. There are no significant differences among the four configurations.

None of the subjective measurements showed any interactions between time and uniform for the four TACAIR uniform configurations. In general, RPE increased in the third walk relative to both the first and second walk in JPACE-ATAGS and 66/P-ATAGS and increased in the third walk relative to the first walk in JPACE-13B/P. The 66/P-13B/P configuration showed no significant increase in RPE throughout the test. In general, TS and TC increased in the second and third walks relative to the first walk in all uniform configurations, and TS and TC in both JPACE-ATAGS and 66/P-ATAGS were greater than in 66/P-13/BP when analyzed over all three walks. PVT data showed no significant differences either across time or among the four TACAIR uniform configurations.

CVC RESULTS

Endurance times on all eight subjects in the two CVC configurations were JPACE 112±21 minutes and 66/P 112±16 minutes. There was no significant difference in endurance time between the two configurations. Two subjects did not complete the JPACE test. One subject stopped at 60 minutes feeling extremely hot with a severe headache, and one subject was removed from testing at 110 minutes for reaching the high heart rate criterion. Two subjects did not complete the 66/P test. One subject was removed at 60 minutes for a medical reason not related to heat stress, and one was removed at 95 minutes because the rectal thermistor slipped and accurate temperature readings could no longer be collected. Five subjects did complete all tests; therefore, the remaining CVC analyses were conducted on the five subjects who completed 120 minutes of testing in each of the two configurations.

Figure 7 shows heat storage (S) in each of the two CVC configurations. The values are JPACE, 42±4 $W \cdot m^{-2}$ and 66/P, 31±7 $W \cdot m^{-2}$. S in JPACE was significantly greater than in 66/P ($p<0.05$).

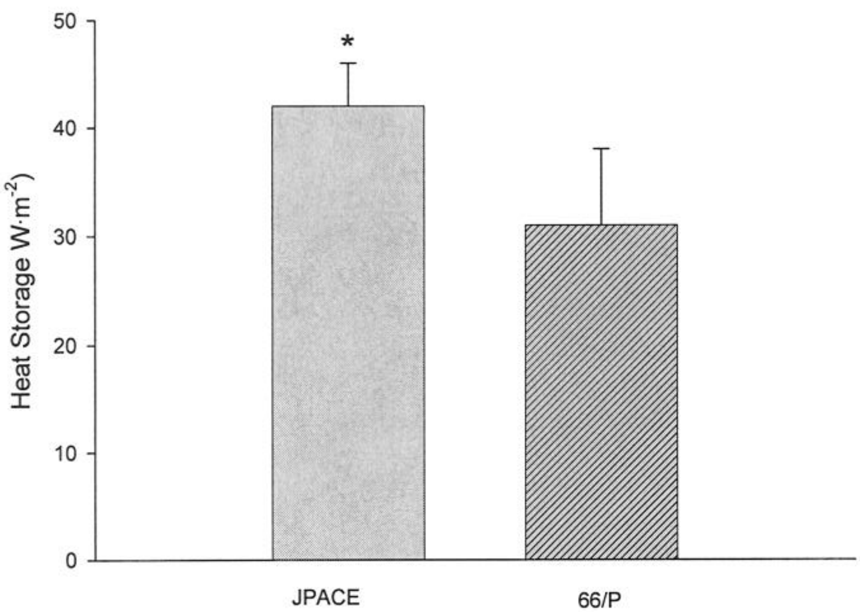

Figure 7. Mean ±SD heat storage during the CVC tests. *JPACE significantly greater than 66/P (p<0.05).

Figure 8 shows core temperature changes over time in the two CVC configurations, with significant differences between JPACE and 66/P appearing at 60 minutes ($p<0.05$). Final core temperature values for the two uniform configurations at 120 minutes are JPACE, 39.0±0.2°C and 66/P, 38.3±0.3°C. Final core temperature in JPACE was significantly greater than in 66/P ($p<0.05$).

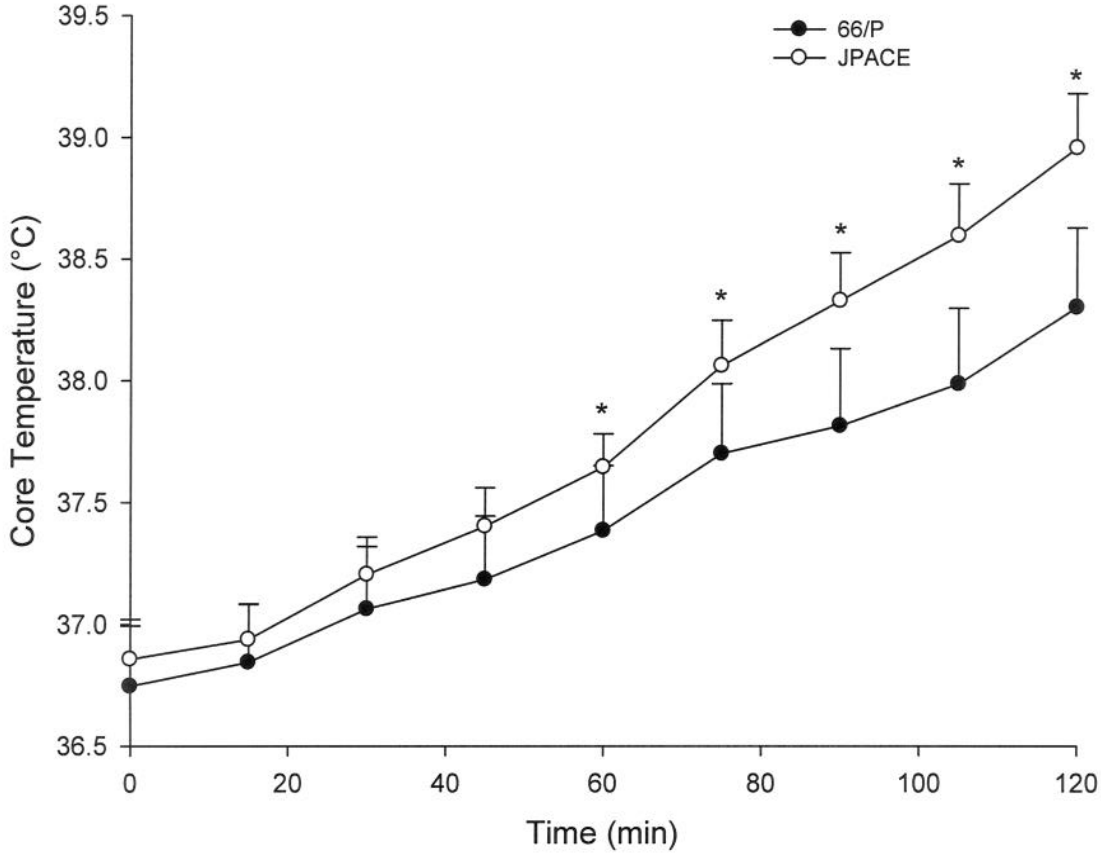

Figure 8. Mean ±SD core temperatures across time during the CVC tests. *JPACE significantly greater than 66/P ($p<0.05$).

Figure 9 shows MWST changes over time in the two CVC configurations, with significant differences between JPACE and 66/P appearing at 45 minutes ($p<0.05$). Final MWST values for the two uniform configurations at 120 minutes are JPACE, 37.2±0.4°C and 66/P, 36.2±1.0°C. Final MWST in JPACE was significantly greater than in 66/P ($p<0.05$).

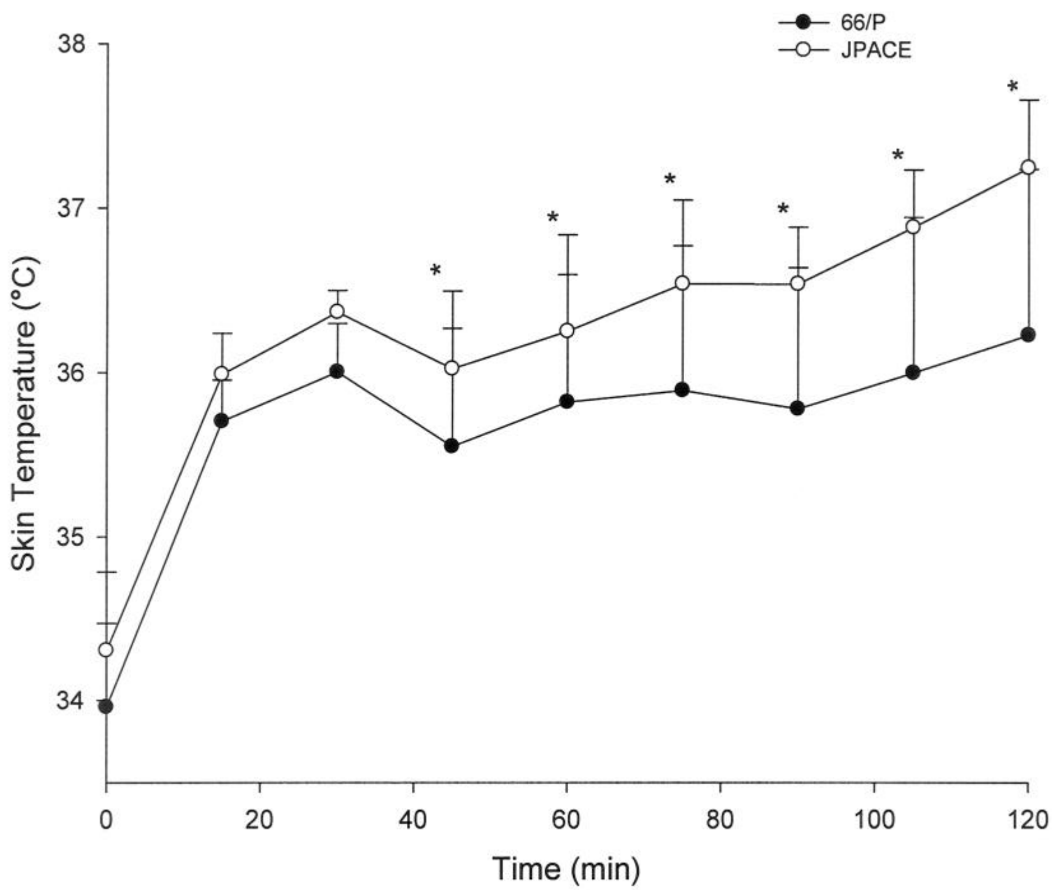

Figure 9. Mean ±SD mean weighted skin temperatures across time during the CVC tests. *JPACE significantly greater than 66/P ($p<0.05$).

Figure 10 shows HR changes over time in the two CVC configurations with significant differences between JPACE and 66/P appearing at 60 minutes ($p<0.05$). Final HR values for the two uniform configurations are JPACE, 159±11 $b \cdot min^{-1}$ and 66/P, 138±13 $b \cdot min^{-1}$. Final HR in JPACE was significantly greater than in 66/P ($p<0.05$).

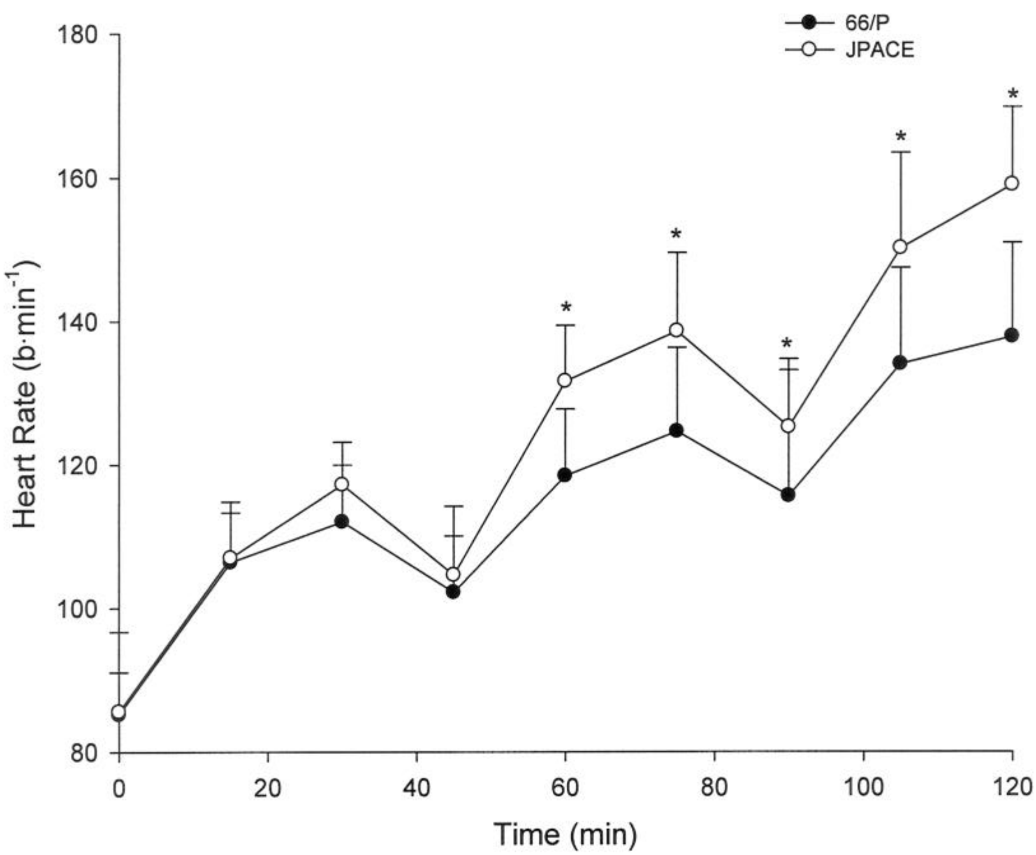

Figure 10. Mean ±SD heart rates across time during the CVC tests. *JPACE significantly greater than 66/P ($p<0.05$).

Figure 11 shows sweating rates in the two CVC configurations. The values are JPACE, 22±12 g·min^{-1} and 66/P, 19±8 g·min^{-1}. There was no significant difference in total sweating rates between the two uniform configurations.

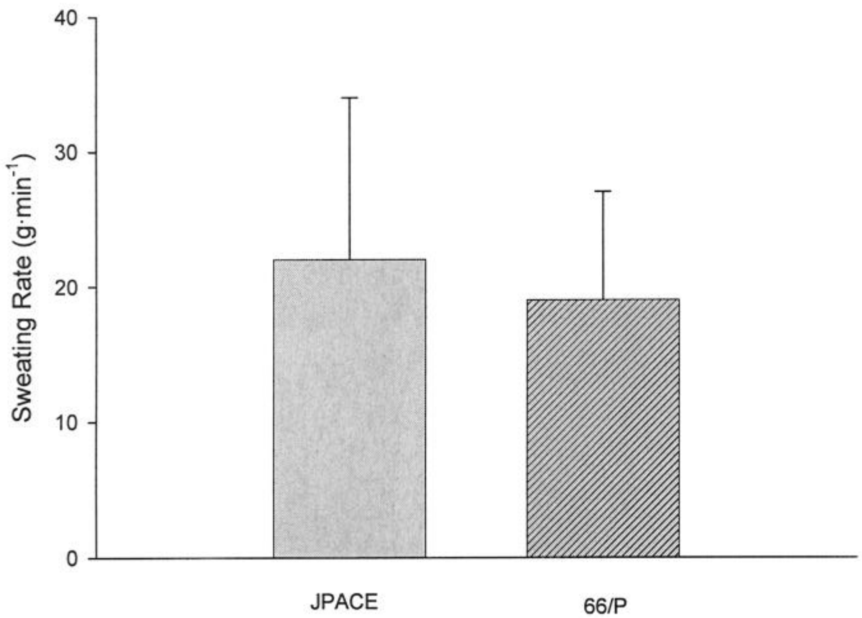

Figure 11. Mean ±SD sweating rates during the CVC tests. There is no significant difference between the configurations.

Figure 12 shows evaporative cooling rates in the two CVC configurations. The values are JPACE, 164±98 $W \cdot m^{-2}$ and 66/P, 160±53 $W \cdot m^{-2}$. There was no significant difference in cooling rates between the two uniform configurations.

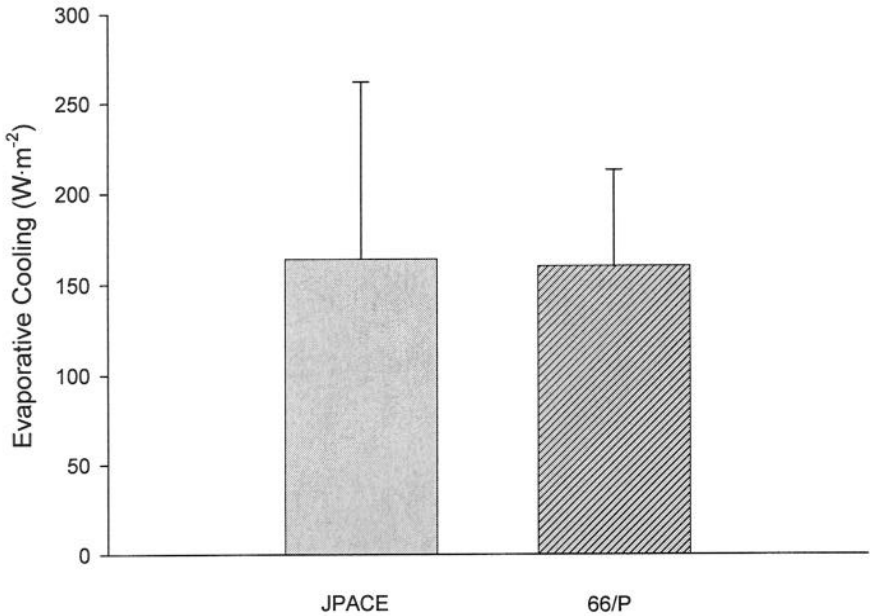

Figure 12. Mean ±SD evaporative cooling rate during the CVC tests. There is no significant difference between the configurations.

None of the subjective measurements showed any interaction between time and uniform in the two CVC configurations. In general, RPE increased in the third walk relative to the first walk in both uniform configurations. In general, both TS and TC increased in the third walk relative to the first walk in both uniform configurations. Additionally, TS in JPACE was greater than in 66/P when analyzed over all three walks. PVT data showed no significant differences either across time or between the two CVC configurations.

RW RESULTS

All eight volunteers completed the entire 120 minute heat exposure in each of the four RW garment configurations: JPACE-NB; 66/P-NB; JPACE-B; and 66/P-B. The currently fielded Air Warrior microclimate cooling system was used to provide cooling to a torso vest in each of the four configurations, with supplementary air blown to the mask in two conditions. The mean cooling provided by the vest in each configuration is JPACE-NB, 161±16 W; 66/P-NB, 154±23 W; JPACE-B, 156±23 W; and 66/P-B, 153±16 W. There were no significant differences in cooling among the four uniform configurations.

Figure 13 shows heat storage (S) in each of the four RW configurations. The values are JPACE-NB, 9±9 W·m^{-2}; 66/P-NB, 12±9 W·m^{-2}; JPACE-B, 11±7 W·m^{-2}; and 66/P-B, 10±8 W·m^{-2}. There were no significant differences in S among the four uniform configurations.

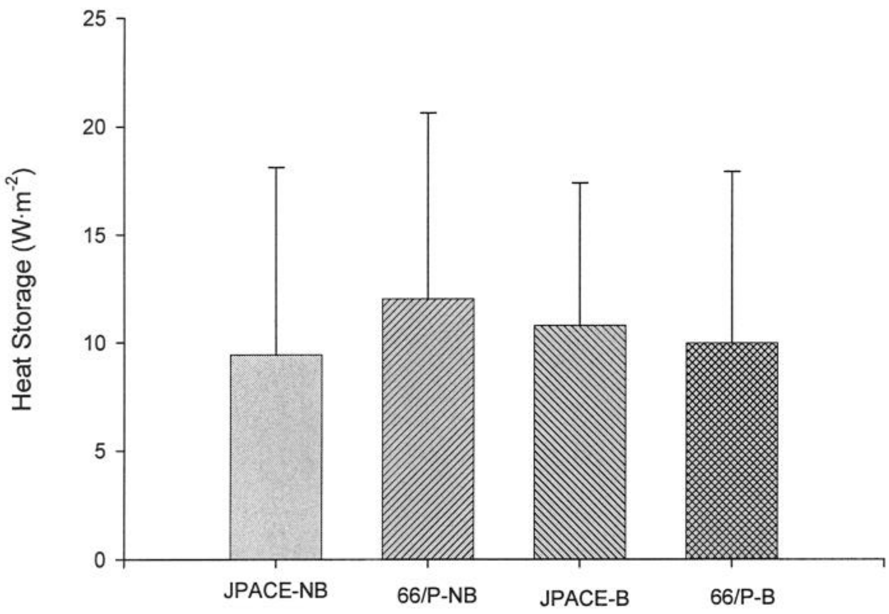

Figure 13. Mean ±SD heat storage during the RW tests. There are no significant differences among the four configurations.

Figure 14 shows core temperature changes over time in each of the four RW configurations. Final core temperature values for the four uniform configurations at 120 minutes are JPACE-NB, 37.53±0.35°C; 66/P-NB, 37.48±0.34°C; JPACE-B, 37.60±0.27°C; and 66/P-B, 37.48±0.22°C. There were no significant differences in core temperature among the four uniform configurations at any time.

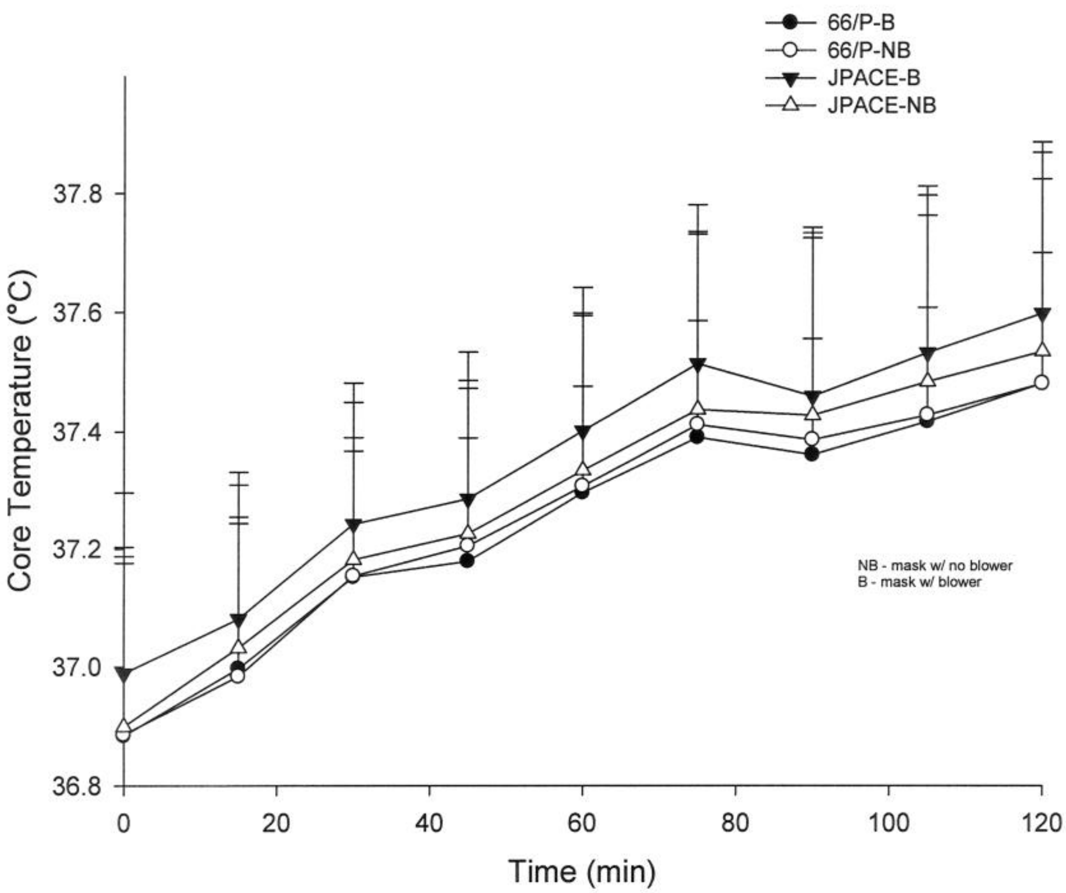

Figure 14. Mean ±SD core temperatures across time during the RW tests. There are no significant differences among the four configurations at any time.

Figure 15 shows MWST changes over time in each of the four RW configurations. Final MWST values for the four uniform configurations at 120 minutes are JPACE-NB, 34.40±0.93°C; 66/P-NB, 34.25±1.07°C; JPACE-B, 34.66±0.76°C; and 66/P-B, 34.24±0.97°C. There were no significant differences in MWST among the four uniform configurations at any time.

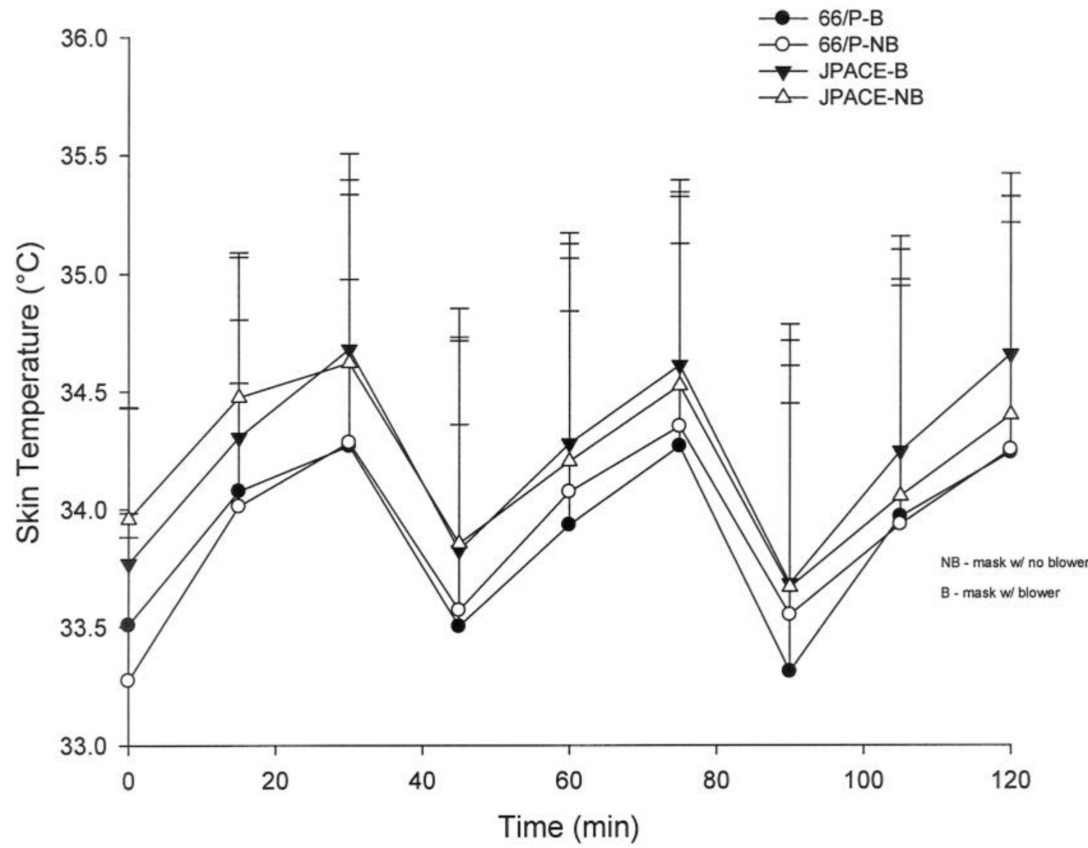

Figure 15. Mean ±SD mean weighted skin temperatures across time during the RW tests. There are no significant differences among the four configurations at any time.

Figure 16 shows HR changes over time in each of the four RW configurations. Final HR values for the four configurations at 120 minutes are JPACE-NB, 121±17 $b \cdot min^{-1}$; 66/P-NB, 117±14 $b \cdot min^{-1}$; JPACE-B, 120±9 $b \cdot min^{-1}$; and 66/P-B, 111±7 $b \cdot min^{-1}$. There were no significant differences in HR among the four uniform configurations at any time. HR in both JPACE-NB and JPACE-B were greater than in 66/P-B when analyzed over all three walks.

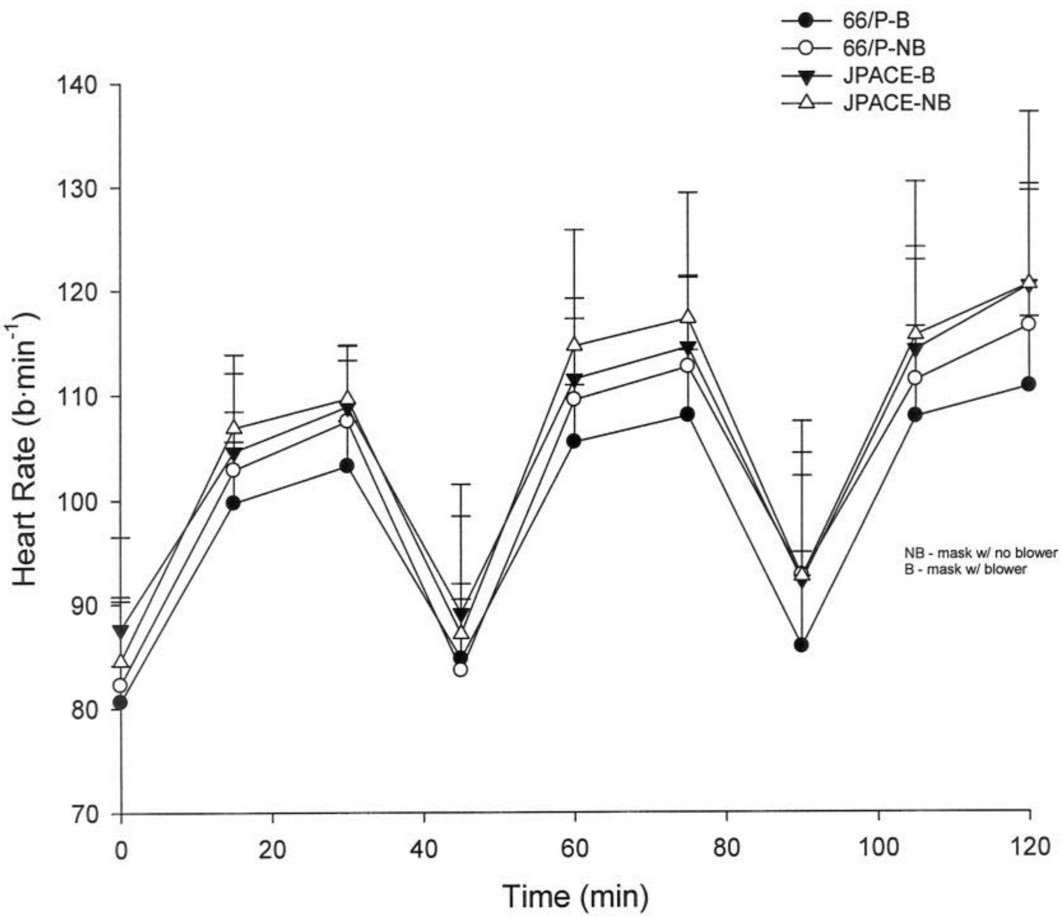

Figure 16. Mean ±SD heart rates across time during the RW tests. There are no significant differences among the four configurations at any time.

Figure 17 shows sweating rates in each of the four RW configurations. The values are JPACE-NB, 12±5 g·min^{-1}; 66/P-NB, 11±4 g·min^{-1}; JPACE-B, 11±6 g·min^{-1}; and 66/P-B, 10±5 g·min^{-1}. There were no significant differences in sweating rates among the four uniform configurations.

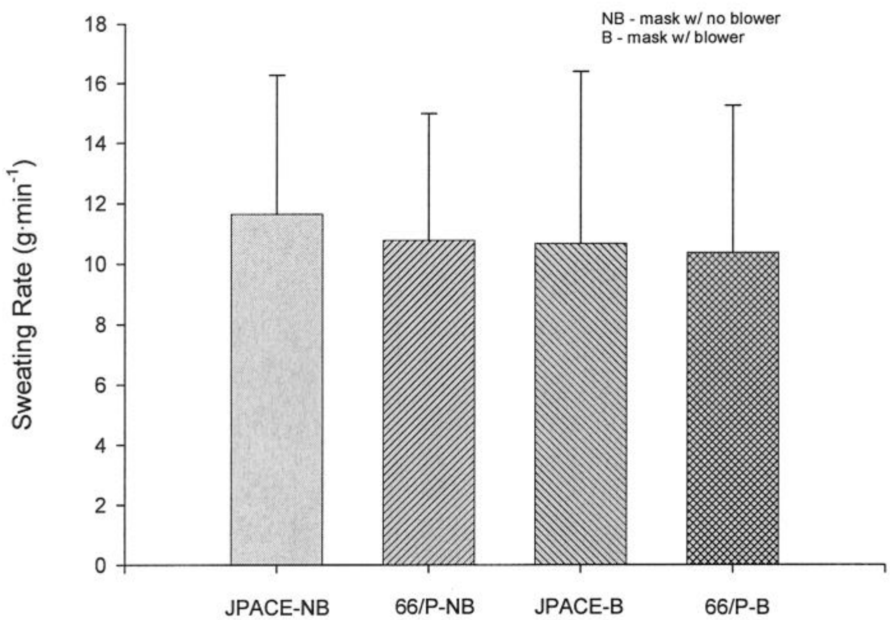

Figure 17. Mean ± SD sweating rates during the RW tests. There are no significant differences among the four configurations.

Figure 18 shows evaporative cooling rates in each of the four RW configurations. The values are JPACE-NB, 96±36 W·m^{-2}; 66/ P-NB, 115±29 W·m^{-2}; JPACE-B, 95±32 W·m^{-2}; and 66/P-B, 82±22 W·m^{-2}. There were no significant differences in evaporative cooling rates among the four uniform configurations.

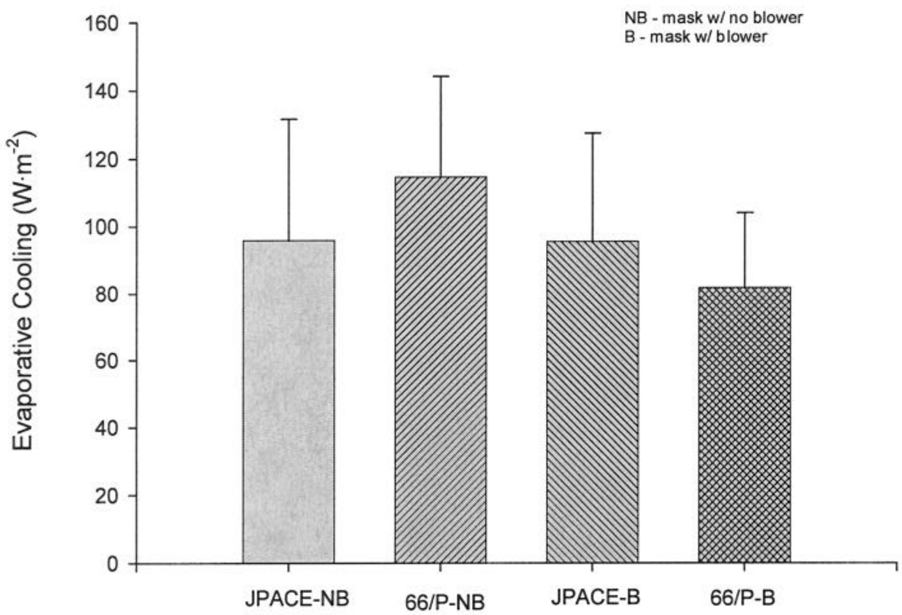

Figure 18. Mean ± SD evaporative cooling rates during the RW tests. There are no significant differences among the four configurations.

None of the subjective measurements showed any interactions between time and uniform in the four RW configurations. TS in 66/P-NB was greater than in 66/P-B when analyzed over all three walks. RPE, TC, and PVT data showed no significant differences either across time or among the four RW configurations.

DISCUSSION

The primary research question for this study was to determine differences in the level of heat strain between the JPACE and 66/P coveralls. The additional equipment worn for full TACAIR, CVC and RW configurations served to confound the physiological responses. Nevertheless, the results still indicate some differences in heat strain between the JPACE and 66/P coveralls when worn in realistic combat configurations. Heat storage provides the best determinant of the impact of the clothing configurations on heat strain because its calculation combines the effect of changes in body core temperature, changes in skin temperature, and changes in body weight over the course of the heat stress exposure.

TACAIR

The physiological responses in the TACAIR tests show that significant differences in the level of heat strain were caused primarily by the impact of the two types of anti-G garments that masked differences between the JPACE and 66/P coveralls. Wearing the ATAGS anti-G garment with either coverall resulted in greater heat storage than wearing the 13B/P anti-G garment with either coverall. Additionally, by 60 minutes into the 2-hour tests, core temperature (Figure 2), skin temperature (Figure 3) and heart rate (Figure 4) all showed increase strain in the two ATAGS anti-G suit configurations relative to the 13B/P anti-G suit configurations.

There was, however, some evidence that the JPACE coverall created greater heat strain than the 66/P coverall. The combination of wearing the JPACE coverall with the ATAGS resulted in a rate of heat storage that approached significance compared with the 66/P-ATAGS combination (Figure 1). Further, the JPACE-ATAGS was the configuration worn by the two subjects who could not complete the 120 minutes of testing.

CVC

The CVC configurations at the MOPP 4 level used for this study added the least additional amount of equipment over the coveralls. Only the soft armor spall vest (worn under the coverall) impeded heat transfer directly from the body to the coverall, and nothing was worn over the coverall in this configuration. This allowed for the cleanest comparison of heat transfer between the two coveralls. It was clear in this configuration that the JPACE created a higher level of heat strain than the 66/P, as indicated by heat storage (Figure 7). Additionally, physiological measurements of core temperature (Figure 8), skin temperature (Figure 9), and heart rate (Figure 10) all showed greater strain in JPACE by 60 minutes of the 2-hour test. Further, the one subject who did not complete a CVC test due to a heat-strain-related issue was wearing the JPACE coverall.

RW

The results of the RW tests clearly show that the impact of the Air Warrior microclimate cooling system overrides any differences that might exist among the four configurations using the two coveralls with and without the addition of a positive pressure blower to the protective masks. None of the physiological measures of heat strain collected in these tests showed any significant differences among the four configurations (Figures 13-18). In addition, the impact of the cooling system is notable in that the heat storage in the RW configurations were approximately one-quarter of that observed with the JPACE-ATAGS configuration in the TACAIR test conducted in a cooler environment, and nearly one-fifth of that observed in the JPACE test in CVC conducted in the same environment as the RW tests. In noting the heat storage reduction in RW relative to CVC, it should be pointed out that the basic clothing configurations were almost identical between CVC and RW systems, except that the RW added a 3.5 kg plate of ceramic armor strapped to the chest, and a load-bearing vest.

CONCLUSIONS

Results from the CVC tests clearly show that the JPACE coverall does not meet the requirement of creating heat strain no greater than a currently fielded CB protective coverall for pilots, as represented by the 66/P. This comparison is confounded by the fact that the 66/P has the least amount of chemical protection of currently fielded CB garments worn by aviators, while JPACE provides a greater level of CB protection (Personal communication, S. Reeps, U.S. Navy Clothing and Textile Research Facility). The higher level of chemical protection provided by the JPACE candidate compared to the 66/P results in a higher level of insulation with the JPACE, as noted in the results. This is at odds with the requirement for reduced heat strain in the JPACE candidate. Whether the level of chemical protection or the issue of reduced heat strain should take precedent is a decision for the managers of the JPACE program.

A sidelight of the tests in the TACAIR configurations is that the use of the ATAGS anti-G suit adds a significantly greater level of heat strain to the user regardless of which coverall is worn with it. For example, the volunteers had an increase in heat storage of 15 $W \cdot m^{-2}$ when wearing the ATAGS over the JPACE compared to wearing the 13B/P over the JPACE. This calculates out to an increase in core temperature of approximately 0.4°C per hour more when wearing ATAGS. This would result in a significantly greater level of heat strain in a pilot flying a prolonged mission or repeated sorties.

Finally, the results of the RW tests using the Air Warrior microclimate cooling system indicate the benefit that the liquid-cooled torso vest would provide to the air crew or combat vehicle crew. Volunteers in the RW tests showed the lowest heat storage and lowest sweating rates of all three sets of configurations, even relative to the TACAIR tests that were conducted in a cooler environment. Heat storage was nearly four to five times greater in the worst TACAIR (JPACE-ATAGS) and CVC (JPACE) configurations, respectively, than in the RW configurations with active cooling. Adding the Air Warrior system or similar microclimate cooling to the JPACE program should be considered to reduce the level of heat strain for all users.

REFERENCES

1. Berglund, L. G. Comfort and humidity. *ASHRAE J.* 40: 35-41, 1998.
2. Borg, G. Perceived exertion as an indicator of somatic stress. *Scan. J. Rehab. Med.* 2: 92-98, 1970.
3. Cadarette, B. S, W. A. Latzka, L. Levine, and M. N. Sawka. *A Physiological Evaluation of a Prototype Air-vest Microclimate Cooling System.* Natick, MA: USARIEM. Technical Report T14-91, 1991.
4. Dinges, D. F., and J. W. Powell. Microcomputer analyses of performance on a portable, simple, visual RT task during sustained operations. *Behav. Res. Meth. Instrum. Comput.* 17: 652-655, 1985.
5. Durnin, J. V. G. A., and J. Womersley. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *J. Br. Nutr.* 32: 77-97, 1974.
6. Gagge, A. P., J. A. J. Stolwijk, and J. D. Hardy. Comfort and thermal sensation and associated physiological responses at various ambient temperatures. *Exp. Res.* 1: 1-20, 1967.
7. Givoni, B., and R. F. Goldman. Predicting rectal temperature response to work, environment and clothing. *J. Appl. Physiol.* 32: 812-22, 1972.
8. Givoni, B., and R. F. Goldman. Predicting heart rate response to work, environment and clothing. *J. Appl. Physiol.* 34: 201-04, 1973.
9. Goldman, R. F. Tolerance time for work in the heat when wearing CBR protective clothing. *Mil. Med.* 128: 776-86, 1963.
10. Henane, R., J. Bittel, R. Viret, and S. Morimo. Thermal strain resulting from protective clothing of an armored vehicle crew in warm conditions. *Aviat. Space Environ. Med.* 50: 599-603, 1979.
11. Pandolf, K. B., L. A. Stroschein, L. L. Drolet, R. R. Gonzalez, and M. N. Sawka. Prediction modeling of physiological responses of human performance in the heat. *Comput. Biol. Med.* 16: 319-29, 1986.
12. Staab, J. E., M. A. Kolka, and B. S. Cadarette. *Metabolic Rate and Heat Stress Associated with Flying Military Rotary-wing Aircraft.* Natick, MA: USARIEM. Technical Note TN98-3, 1998.
13. Young, A. J., M. N. Sawka, Y. Epstein, B. DeCristofano, and K. B. Pandolf. Cooling different body surfaces during upper and lower body exercise. *J. Appl. Physiol.* 63: 1218-1223, 1987.